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The Method to Diagnose Local Abnormalities in Windings of High Temperature Superconducting Transformer During Load Changing

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Abstract

We propose a new monitoring system for high-temperature superconducting transformers. This system consists of pick-up coil pairs arranged outside the cryostat for measuring electric fields and magnetic fields. In a previous paper, it was confirmed that our system can detect the local abnormalities in a test transformer windings when its load doesn't change. In actual operation, however, the transformer load is always changing during practical operation. Therefore, the measured signal also changes with the load change even when abnormalities don't occur in the windings of the transformer. In this paper, we propose a method to cancel the change of the signal with the load change. In this method, our measuring signals are normalized by the power of a current. The purpose of this paper is to confirm that normalized signals don't change with the load change. Local abnormalities in the transformer windings were successfully detected and signal changes due to the changing load of the transformer were canceled.

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Keywords: transformer; monitoring system; quench; ac loss

1. Introduction

Development of high temperature superconducting (HTS) transformers is ongoing [1]. HTS transformers have the advantages of high efficiency, small size and lightweight compared with conventional transformers.

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Electric power devices such as transformers, which are used in power transmission and distribution systems, require high reliability. Therefore, these devices must be constantly monitored to check whether unusual events have occurred. Particularly in the case of HTS transformers, the importance of a monitoring system is higher than in the conventional copper transformers due to the risk of a hotspot which could be caused by both low thermal diffusivity and high current density in HTS transformers. Some quench detection systems for superconducting systems have been developed [2-6]. Although the most reliable system is the balance voltage method using center voltage taps, the system has high risks related to the occurrence of serious troubles such as high voltage sparking. Therefore systems in general use are not suitable for monitoring superconducting transformers systems [7].

In order to develop a new monitoring system with safety, reliability, sensitivity, and utility, we have proposed a new monitoring system by applying the Poynting's vector method [7-10]. We have so far shown that our system can detect local abnormalities occurring in the windings of HTS transformers when the load of the transformer doesn't change [7]. In practice, however, the transformer load always changes. Signals obtained by our system change with the change of the load for reasons mentioned in chapter 2. Therefore, it is difficult to judge which of the factors, the load or the winding conditions, lead to a change of the measured signals.

In this paper, a new method to cancel the change of measured signals with load change is proposed, and then the validity of the method is shown experimentally on a test transformer wound with Bi-2223 multifilamentary tapes.

2. Principle of the monitoring system and proposal of a new method to cancel the influence of load change on measured signal

To measure abnormalities, Poynting's vectors as electromagnetic energy flows are measured around the superconducting transformer. If some abnormalities occur in the windings, some changes in Poynting's vectors into the superconducting transformer should be observed. Therefore, the system can detect abnormalities in windings by means of monitoring temporal changes of Poynting's vectors.

The Poynting's vector, $\boldsymbol{P}$ is given by the cross-product of electric fields $\boldsymbol{E}$ and magnetic fields $\boldsymbol{H}$ ($\boldsymbol{P} = \boldsymbol{E} \times \boldsymbol{H}$) around the transformer. $\boldsymbol{E}$ and $\boldsymbol{H}$ can be obtained by using pick-up coils as shown in Fig. 1. There are two kinds of pick-up coils for measuring local electric fields and local magnetic fields (hereafter we call these pick-up coils, PC-E and PC-H, respectively). Details of the method to measure electric fields have been explained in Refs. [8-10]. The energy flows per cycle W is calculated by one cycle integration of $\boldsymbol{P}$. W is the loss component of energy flow (hereafter called LEF) [7]. Therefore, LEF corresponds to ac losses in the winding. If abnormalities occur in the windings of the transformer, ac losses are affected by the abnormalities. So a change of LEF is observed. Therefore, it is necessary to measure the loss component of the signal voltages from PC-E. In this system, the inductive component of the signal voltage from PC-E is cancelled by using the signal voltage from PC-H.

Ac losses in the windings of the transformer are influenced by both temperature and magnetic fields. Magnetic fields change with change of the load. Therefore, LEFs are affected by temperature and load. Consequently, it is difficult to judge which of the load or the condition of windings lead to a change of the measured signals.

In general, the ac loss properties of HTS transformers can be expressed as the power function of the load currents [11]. Therefore, it is considered that measured signals from our system can also be expressed as the power function of the load currents. It indicates that the measured signals divided by the power of the currents are identical. So, our proposed new method to cancel influences of load change on measured LEFs is to normalize the LEFs by the power of a current.

3. Experiments

3.1. Experimental set up

The experiments were carried out for the small size HTS transformer shown in Table 1. The rated power of this transformer is 800 VA. The rated voltages and currents of primary/secondary windings are 22.5/45 V and 35.6/17.8 A, respectively. Leakage impedance of this transformer is 7.0 %, which in comparison is equal to or smaller than devices currently used. The winding tape is Bi-2223 multifilamentary tape whose critical current is 115 A in self

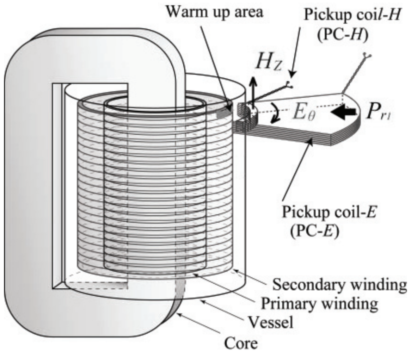

Fig. 1. Example of pick-up coil arrangements to measure local Poynting's vectors around the superconducting transformer. In this system, pairs of PC−E and PC-H are used to obtain the loss component of Poynting's vector as electromagnetic energy flow. PC-E and PC-H are pick up coils for measuring electric fields and magnetic fields, respectively.

Table 1. Parameter of superconducting transformer.

Phase	1
Rated voltage	22.5V/45V
Rated current	35.6A/17.8A
Rated capacity	800VA
Leakage impedance	7.0%
Cross sectional area of iron core	1225cm^2

Table 2. Parameters of pick-up coils.

	PC -E	PC-H
Number of turns	20	80
Length of inner arc	58.8mm	58.9mm
Length of outer arc	137.4mm	62.8mm

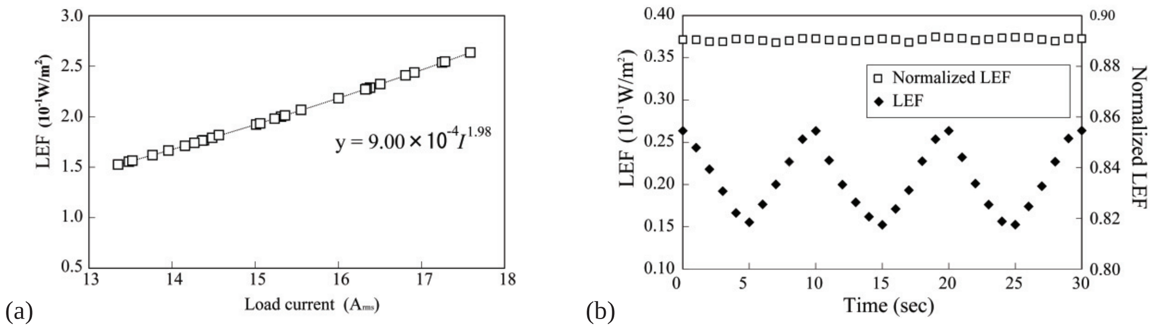

Fig. 2. Experimental results, (a) current dependence of LEF, LEF is proportional to about the 2nd power of the load current. (b) LEF and normalized LEF. Normalized LEFs don't change, although LEFs change with load change.

fields and 77.3K. Width and thickness of the tape are 4.2 mm and 2.2 mm, respectively. In this experiment, local abnormalities were generated by means of blowing in nitrogen gas. The gas was blown on to the winding tape on the edge of the secondary winding as shown in Fig. 1. The bobbin of the winding has two holes at its edge point corresponding to the warm up area. Nitrogen gas was blown on to the winding tape through these holes. Winding temperatures around the warm up area are shown in Fig. 1. Winding temperatures were measured by using type E thermocouples. The pick-up coil pair to measure LEF was set near the warm up area as shown in Fig. 1. The parameters of the pick-up coils are shown in Table 2.

3.2. Results

Firstly, in order to clarify the dependences of LEF on the current of the transformer, LEFs were measured around the transformer without abnormalities while changing the load of the transformer. As the load of the transformer, a sliding resistor was connected to the transformer. The load current was varied repeatedly from 17.5 A to 13.8 A, every 10 seconds. Current frequency was 50 Hz. The results are shown in Fig. 2 (a). From this figure, it is found that the LEF is proportional to about the 2nd power of the load current. Fig. 2 (b) shows temporal changes of LEFs and normalized LEFs by the 2nd power of the load current. The normalized LEFs are obtained by our proposed method explained in the previous chapter. The normalized LEFs are identical, although actual LEFs change with load change.

Next, in order to confirm that our proposed method can cancel the change of measured signal with a changing transformer load even when abnormal conditions occur in the transformer, LEFs were measured under operation while changing the load. Abnormalities are generated locally in secondary windings by blowing nitrogen gas onto

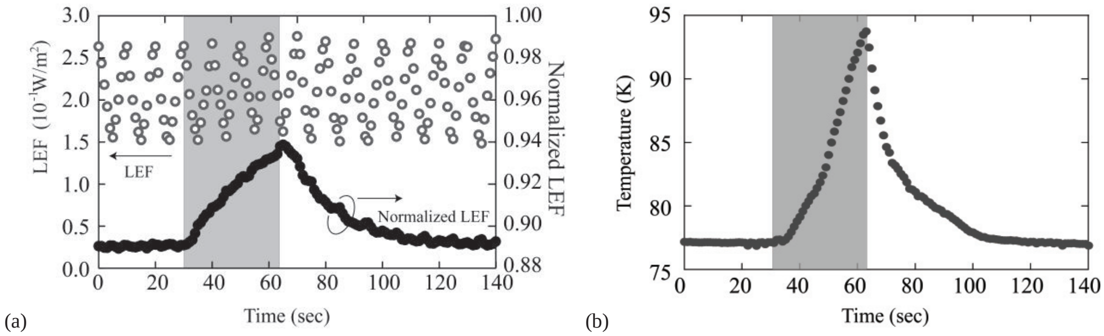

Fig. 3. Experimental results, (a) LEF and normalized LEF, open and solid plots represent LEF and normalized LEF, respectively. LEFs are drastically changed with load change in spite of occurring abnormalities. Normalized LEFs are almost identical unless nitrogen gas is blown in. It is clear that change of normalized LEF corresponds to change of winding conditions. (b) Temperature of the primary winding.

the winding. Obtained LEFs were then normalized by the 2nd power of the load current of the transformer. The results are shown in Fig. 3 (a). In this figure, LEF and normalized LEF are plotted. The horizontal axis is time. The grayed area in the figure represents the time during which nitrogen gas was blown in. Measured LEF changes drastically with load change even when abnormalities don't occur. In contrast, the normalized LEF are almost identical unless winding temperature rises. It is clear that changes of normalized LEF correspond to change of winding conditions as shown in Fig. 3 (b), which shows the temperature of the winding.

4. Conclusion

We have proposed a new method to cancel the change of measured signals with load change, and experiments were carried out to confirm the validity of the method. First, the experimental results show that the loss component of energy flows can be expressed as a power function of a current. Next, through changing the load we generated local abnormalities in the windings of a high temperature superconducting transformer. The experimental results show that local abnormalities in the windings of the transformer were successfully detected and that the change of the measured signals with change of the load of the transformer was cancelled. This indicates that our system has validity as a diagnostic method for local abnormalities in the windings of HTS transformers under practical operation with a changing load.

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